NATIONAL ECOLOGICAL OBSERVATORY NETWORK

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GRAND CHALLENGES IN ECOLOGY

A number of ecological "grand challenge research issues" confront our nation and world. To address these issues requires a holistic understanding of the earth's ecology. Research integrated from the molecular to ecosystem levels, from nanometer to continental scales and from seconds to geological time, which is vital for this type of understanding, was impossible in the past. However, recent advances in genomics, information technology, miniaturized analytical instrumentation, wireless technology, and nanoscale devices now enable integrated environmental research and herald new ways of doing science and a new era of ecological understanding. **NEON: the National Ecological Observatory Network** was developed and designed by the ecological research community to be a tool, which by capitalizing on scientific and technological advances, will allow the broadly-defined community of field biologists to analyze, understand and forecast **the nature and pace of biological change** at local to continental scales. They envisioned that NEON would integrate information across many disciplines, including hydrology, ecology, genomics, engineering, and computer science, thereby allowing us to understand and forecast the causes and consequences of ecological dynamics at multiple spatial and temporal scales.

Examples of ecological "grand challenge research issues" that could be addressed with NEON include:

> **Biogeochemical Imbalances**, such as nitrogen eutrophication in terrestrial, freshwater and coastal zones, are one of the most serious challenges to the integrity of ecological systems. These challenges have significant management and economic implications for the sustainability of freshwater and coastal systems. For example, production, distribution and deposition of elements, such as nitrogen and phosphorus, in fertilizers are regional- to continental-scale phenomena that can reduce biodiversity in terrestrial ecosystems and create extensive anoxia in coastal zones. What happens in the Great Lakes Region can affect Mississippi's coastal zone, and nitrogen-enriched air from the Midwest is depositing nitrogen on soils in Maine.
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> **Carbon Dynamics** vary within and among ecosystem types ranging from human-dominated urban environments to uninhabited boreal wetlands. For example, carbon fluxes result from fundamental ecological processes of photosynthesis and respiration. There are hotspots and cold spots in carbon fluxes in space and time. Understanding and managing such fluxes have national and international implications. To develop integrated knowledge about the causes and consequences of carbon processing, sequestration, and flux requires research infrastructure and measurements at spatial and temporal resolutions that do not exist currently.
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> The ecology of **emerging infectious diseases** is a phenomenon of critical importance that is now recognized as an ecological and environmental research challenge being played out at regional to continental scales. Addressing this problem requires understanding patterns of land use change, density and distribution of disease vectors, the molecular basis of host-parasite interactions, and species dispersal in space and time. Moreover, no infrastructure or organization is in place that can rapidly investigate the ecological aspects of a disease outbreak, something akin to how the CDC responds to an outbreak of human pathogens.

Invasive species have dramatically altered the structure and function of ecosystems worldwide. Currently, research on invasive species is reactive because we lack a comprehensive framework for confronting invasive species before they spread. A new approach is needed which can form the basis for a- proactive discovery and mitigation programs that can be implemented before eruptions in invasive species become economically or environmentally damaging. Recent technological advances such as genome sequencing can greatly enhance our understanding of the invasiveness of species; while new remote sensing and analysis techniques can help predict the susceptibility of habitats to invasion.

Marked changes in the biodiversity of the earth are occurring. Whether a reduction in the number of species or in the genetic diversity within species at local, regional or continental scales will impact US ecosystems and how is currently unknown. Understanding the interaction of species within ecosystems and the role of **biodiversity and ecosystem dynamics** are therefore urgent research challenges.

A comprehensive understanding of the causes and consequences of **coupled human-natural systems dynamics** is needed. A gradient of human impacts exists globally, thus, humans can no longer be considered separate from natural systems. Rather, humans are key components of ecosystems and their local actions and decisions have far ranging impacts on distant natural and human systems. What is needed is an integrated research approach to understand the interactions among, and feedbacks between, social and ecological systems. Research coupling human-natural systems is needed to increase understanding and to facilitate ecological forecasting about the pressing environmental challenges facing this nation.

NEON: The National Ecological Observatory Network

Background & Planning

As early as 1991 (Lubchenco et al., The sustainable biosphere initiative *Ecology* 72: 371-412) the ecological research community recognized the need for an integrated, regional- to continental-scale observation system and research platform. Recent reports from the National Academy of Sciences (e.g., *Grand Challenges in Environmental Sciences (2000)* and *Global Environmental Change Research: Pathways for the Next Decade* (1999) and President's Council of Advisors on Science & Technology (PCAST): *Teaming with Life* (1998) reiterated the need for comprehensive research infrastructure to address regional or continental scale questions. In addition, over the past 20 years, the Long-term Ecological Research (LTER) program has demonstrated the value of long-term, integrated, site-based research for obtaining a basic understanding of ecological systems.

It is now widely recognized that a more complete understanding of ecological systems is possible but only if site-based research can be placed into a larger, more integrated regional context. To do so requires a broad scale research platform capable of real-time, continuous measurements of multiple environmental parameters ranging from the molecular to ecosystem level, from nanometers to continental scales and from seconds to geological time. Previously, conducting research at multiple scales, especially at regional or continental levels, was impossible because we lacked the technology, scientific instruments and facilities needed to collect and synthesize the required complex information. Fortunately, recent advances in genomics, wireless technology, miniaturized analytical instruments, and information technology, coupled with the promise of new tools from discoveries in nanoscience and engineering now make it possible to create such a platform.

Multiple reports, the Long-term Ecological Research (LTER) program experience, and the recent technological developments noted above, led NSF to spend approximately $1.8 million from 1999-2002 on community-driven planning activities to develop a detailed scientific agenda and blueprint for a research platform that could be used to conduct ecological research at multiple scales. These planning activities yielded specific recommendations on platform structure, core measurements, information technology needs, network size and configuration, and management and governance protocols. See www.sdsc.edu/NEON for reports from eight planning workshops. NEON, the outcome of these planning efforts, is designed to be a comprehensive, state-of-the-art research platform that will enable a new type of research to obtain the integrated understanding of the environment needed to address ecological grand challenges. Given the time course of many of these phenomena, NEON is designed to have a 30-year operational lifespan.

MISSION AND OBJECTIVE OF NEON

The mission of NEON is to establish and sustain the scientific infrastructure and develop the intellectual capital needed to address critical questions about changes in ecological systems and to evaluate the impacts of those changes.

The objective of the NEON program is to build a fully integrated distributed national network of environmental observatories and to provide the technical means and support personnel to achieve the mission of NEON.

USERS

The primary purpose of **NEON** is to serve as an integrated research tool that will be used by a large number of biological, physical and social scientists and engineers to achieve a better understanding of our nation's ecosystems. The NEON concept is similar to that of a telescope, which is designed as a multi-user instrument designed to make integrated sets of measurements.

The research community will obtain access to use **NEON** via submission of research proposals, which will be evaluated and funded by NSF programs using the merit review process. This creates an open access policy that will allow **NEON** infrastructure to be used by a wide array of scientists with the most creative ideas.

In addition, local, state and national decision makers will use results from **NEON** research to inform planning and policy decisions. Kindergarten through post-graduate students and teachers will use **NEON** information for educational activities and **NEON** facilities for research. Finally, the American public will use **NEON** to get up-to-date information about environmental issues of interest to them.

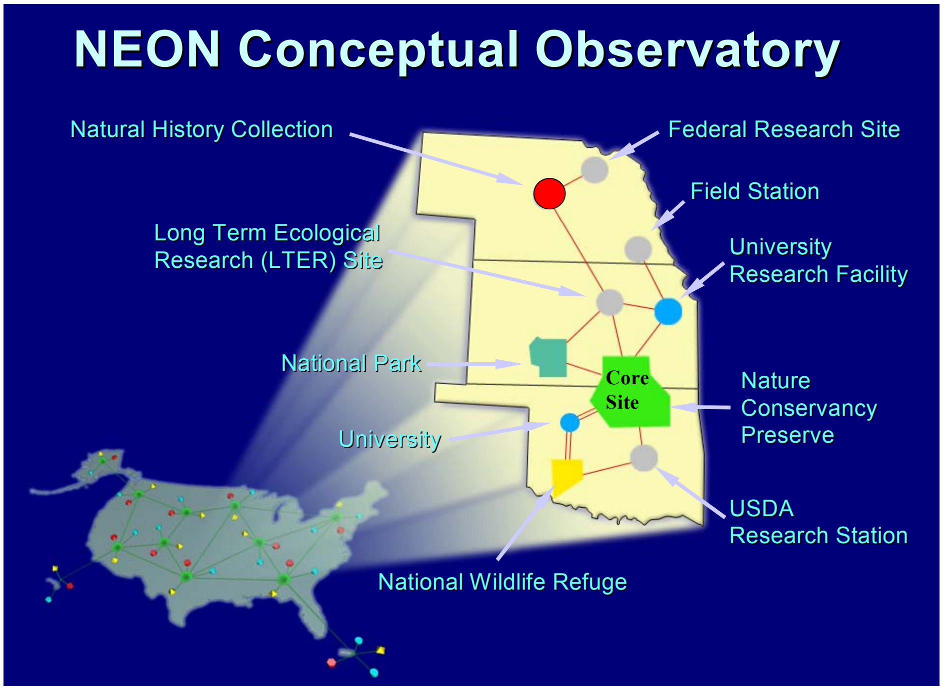
NEON DESIGN

NEON will be a network of networks, a system of environmental research facilities with cutting-edge instrumentation. It will enable integrative research on the nature and pace of biological change at local, regional and continental scales. **NEON's** advanced technologies and continental scale connectivity are designed to measure and analyze the variables needed to understand the structure and function of ecosystems. New environmental technologies like wireless sensor arrays and real-time nanoscale analytical field instruments will be developed, tested and deployed by **NEON**. Only with such a comprehensive capability will we be able to tackle the ecological grand challenges.

NEON will be composed of a number of networked regional observatories. Each observatory will be composed of a core site and associated satellite sites linked via cyberinfrastructure. The observatories will be geographically distributed across the ecoregions of the US. NEON will also include a Coordinating Unit.

When the full compliment of observatories are established and all observatories are linked, NEON will be a network of networks for local to continental scale field biology research.

A SINGLE REGIONAL OBSERVATORY



Each observatory will have a regional footprint (Figure 1) made up of heavily, moderately and lightly instrumented field sites and associated field and laboratory facilities. NEON will leverage existing infrastructure and programs, plus upgrade, enhance and add to infrastructure at core and satellite sites. Advanced computational infrastructure will provide the connectivity that will turn these core and satellite sites into an integrated regional research tool. Together, the network of observatories will be a fully integrated continental scale research platform.

Figure 1. An example of a possible **NEON** observatory showing the partners, sites, and facilities that could potentially be linked to form a regional footprint.

CORE AND SATELLITE SITES

Based on workshop recommendations, NEON observatories will be developed around the "Octopus Model" (Figure 1) in which there is a central core site and a number of associated satellite sites that together provide the regional footprint of an observatory.

Each NEON observatory will be a network of sites that collectively provide the necessary breadth and depth of field facilities, research infrastructure, and analytical capability for comprehensive, state-of-the-art research in field biology. The nucleus of an observatory is the intensively instrumented **core site**. The core site could be a biological field station, a US Forest Service Experimental Watershed, a LTER site, a National Park, a US college or university campus, a marine lab, a research station of other federal, state, and local agencies, a Nature Conservancy preserve, etc. This list is not intended to be exhaustive, or prescriptive, it is merely suggestive of the range of possibilities for a **core site**.

It is at the **core site** where intensive, specialized research infrastructure, e.g. field-based sensor arrays, flux towers, meteorological superstations (see Standard Measurements and Instrumentation: Climate and Hydrology section in appendix A), will be deployed to maximize the capability of data collection, processing, and analysis. In addition, it will be essential for each observatory to have a formal collaboration with at least one research sample collection facility, such as a natural history museum.

Satellite sites will contain varying amounts of field instrumentation and thus varying degrees of research capability. These sites will be linked to the core site via high-speed Internet connections. Satellite sites could be any one of the types of sites mentioned above in the description of a core site. The basic difference between a core and satellite site is that the core site will be more heavily instrumented and have greater analytical capability than a satellite site.

NEON will generate a large number of samples for analysis. Routine analyses will be conducted at individual NEON observatories using existing standardized protocols or ones developed by the NEON research community. However, some analyses, e.g. genome sequencing, tree ring analyses, stable isotope determinations, chemical assays, of large numbers of samples are more feasibly and efficiently done at specialized analytical facilities rather than at individual **NEON** observatories. Whenever possible, **NEON** will outsource samples to existing federal or commercial analytical facilities.

DEVELOPING PARTNERSHIPS

A database of current federal and state, field-based ecological programs is being developed by the American Institute of Biological Sciences (AIBS) to serve as an information resource and clearinghouse for consortia that are developing **NEON** proposals. The purpose of the AIBS effort is to facilitate academic researchers establishing connections with existing federal and state programs. Other outreach efforts continue, as well. For example, NSF has established a dialogue with the Environmental Protection Agency's Tribal Science Council to develop a mechanism for incorporating traditional knowledge and culturally based observations into observatory activities and databases. Finally, as with the International LTER Network, NSF anticipates that NEON will lead to strong research collaborations with nascent NEON-like activities in Australia, the EU, and other countries.

NETWORK SIZE AND CONFIGURATION

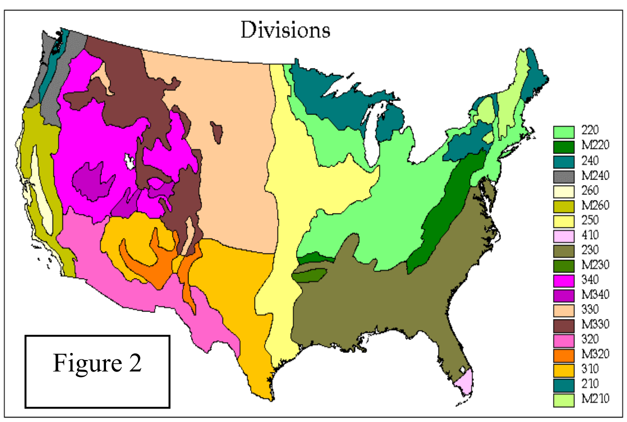


Figure 2

The cost estimates and design for NEON have been developed and refined over the course of eight workshops. These activities led to the identification of infrastructure needs for a regional footprint. Following numerous planning activities and community-based discussions, the research community recently recommended that <u>17 observatories</u> are needed for a fully functional NEON. This would include 16 observatories distributed across the United States and one in Antarctica. This number was based on the US Forest Service defined biomes and ecoregions of the US (Figure 2), plus the linkage to Antarctica. The goal is to assure that observatories are distributed nationally, and that they have the capability of developing an integrated analysis of the major biomes in the United States. Large biomes may contain two full observatories; smaller areas may be a subset of a single observatory. This approach allows for a statistically powerful, stratified random design for **NEON**. Observatories will be proposed and consortia developed by teams but the final selection of observatories and the Coordinating Unit will be decided through a competitive merit review process. When complete NEON will be a network of sites that are distributed within and among the major biomes and ecoregions of the US.

INTEGRATION – THE NEON COORDINATING UNIT (NCU)

Coordination and standardization will be key to the success of **NEON**. A **NEON** Coordinating Unit (**CU**) will manage integration across the network of observatories. Specific objectives of the **NEON-CU** will be to (1) develop and implement, in conjunction with **NEON** observatories, core equipment, core data measurements and data quality and control standards, (2) develop and implement information management standards, practices and data accessibility policies, (3) provide technologies for storage, retrieval, manipulation, analysis, and visualization of complex data sets, (4) integrate **NEON** activities with existing federal, state, and local programs, (5) schedule usage, (6) integrate activities across the network, (7) coordinate interactions and communication among **NEON** observatories, (8) identify and test leading edge technologies for environmental research, (9) provide training to the scientific community and other users, and (10) coordinate outreach activities with the general public.

FUNDING BREAKDOWN

INDIVIDUAL OBSERVATORY

Based on the planning workshops, it has been determined that a fixed cost of $20 million per observatory excluding inflation would allow each observatory to:

1. acquire the Network-wide suite of standard instrumentation, measurement and analytical capabilities;
2. develop high speed Internet portals and information technology requirement; and
3. develop region-specific research infrastructure.

The exact disbursement of the $20 million will vary among observatories, and flexibility within boundaries in this allocation of funds has been recommended from the start.

- <u>Information Technology:</u> Up to $3.0 million (~ 15%) will be needed to create an information technology infrastructure component for each observatory designed to maximize data capture, storage, management, manipulation, visualization, transmission, and sharing. Approximately 10% will be used for sensor development.
- <u>NEON Standard Installation</u>: Approximately $5.0-$8.0 million (~25-40%) will be used to enhance, upgrade, and add to existing infrastructure. For example, a **NEON** core site may already have a fully instrumented flux tower but that tower may not be co-located with a fully instrumented hydrological network and complete meteorological measurement capability. In that case, funds would be used to purchase and install the hydrology and meteorological instruments.

- <u>Construction/Renovation:</u> Installation of new equipment and facilities may require remodeling or new construction. Up to $4.0 million (~20%) can be used for construction/remodeling subject to a 1:1 match from non-federal dollars from the managing consortium.

- <u>Site Specific Infrastructure:</u> Finally, because each **NEON** will have a regional focus, as well as being part of a national network, between $8.0 and $11.0 million (~25-50%) will be allocated to site-specific infrastructure. A **NEON** observatory in a forested region, for example, may want to construct a canopy crane and a multi-tiered canopy access scaffolding system that is fully instrumented for 3-D measurements of forest canopy structure and function. Such a network could cost $3.0 million; yet, it would provide a currently unavailable research platform to study the temporal dynamics of gas fluxes in the canopy or spatial structure in the genomic architecture of viral infections on tree leaves. In grasslands, on the other hand, an observatory could use **NEON** funds to construct a replicated set of large-scale climate manipulation shelters, which could cost $2.0-3.0 million. Such shelters would be fully instrumented to assess the impacts of, for example, changes in precipitation regime on net primary production and soil carbon storage capacity. Because of the scale of such shelters, they could also be used by behavioral ecologists to measure and model the impacts of climate change on the behavior and population dynamics of grasshoppers, a key herbivore in grassland ecosystems.

A SAMPLE NEON OBSERVATORY BUDGET

An example breakdown of funds for operations & maintenance, laboratory and field-based infrastructure for an observatory is found in Tables I and II.

TABLE I. NEON Budget: Operations & Maintenance

An EXAMPLE ($$ in Thousands)

	Year 1
Operations and Maintenance (annual costs)	**3,000**
--Staff	1900
Informatics Experts	650
Technical Experts	1100
--Networking	
--Mass Spec Expert	
--Field Equipment Expert	
Other Personnel	150
--Fringe Benefits	175
--Indirect Costs	622
--Other Direct Costs	478

OPERATIONS & MAINTENANCE

Each NEON observatory would require $3.0 million per year for maintenance and operations excluding inflation. These funds would cover the personnel costs, materials and supplies, some periodic upgrades of equipment, travel and various support activities (see details in Table I).

TABLE II. NEON Budget: Facilities & Equipment

Facilities & Equipment (dispersed over 3 years)	**20,000**
Biological Infrastructure	
Mass Spectrometers	1300
High Performance Liquid Chromatograph	100
DNA Sequencing Prep	350
Advanced photon microscope	400
Confocal Microscope	150
Ultracold freezers	250
Incubators, Growth chambers	500
Radio and Acoustic Telemetry Arrays	200
Minirhizotrons	100
Biological collection facility	300
Digital Museum technology	200
Ultra Cold Tissue Archives	150
Site Specific Infrastructure (NMR, specific isotope chambers)	3000
TOTAL Biological & Genomic Infrastructure	**7000**
Chemical Infrastructure	
Amino Acid Sequencer	250
Carbon, Hydrogen, Nitrogen Analyzer	350
CO-2 analyzer	100
Atomic Absorption Spectrophotometer	100
Portable Gas Chromatographs	200
Chem-lab on a chip	100
Electronic Nose/Tongue Sensors	100
Site Specific Infrastructure (automated processors)	200
TOTAL Chemical Infrastructure	**1400**

Table II. Continued

Physical Infrastructure	
Sunphotometer	300
Current Meter	200
Tide station	125
Wave rider	50
Sedimentation table	150
Turbidity Sensor	50
Salt water circulation system	150
Meterological Stations	350
Hydrologic facility	400
Lidar	200
Eddy Flux Correlation Towers	500
Multiparameter soil probes	50
Multi-parameter Sondes	50
Global Positioning System	25
Site Specific Infrastructure (Canopy access crane, automated rainfall manipulation shelters) and instrument development	6000
TOTAL Physical Infrastructure	**8600**
Information Technology/Computation/Networking	
Computational facility	500
Date & Info Mgmt Systems	500
Geographic Information System	200
Satellite/High speed link Internet2 link	1000
Video conference facility	100
Wireless equipment	400
Sensor Webs	300
TOTAL Information Tec./Comp. Networking	**3000**

STANDARD MEASUREMENTS, INSTRUMENTION, AND INFORMATION TECHNOLOGY

Standard measurements and instrumentation requirements have been distilled from numerous NEON planning workshop reports (http://www.nsf.gov/bio/neon/reports.htm). This suite of instruments was selected to provide an integrated set of standardized measurements and analytical capability to address the grand challenges in ecology. The standard measurements and instrumentation needs listed in Table II will facilitate quantitative and integrative analyses of:

- Climate and Hydrology: NEON would provide opportunities to develop instrumentation at the Core Observatory and within satellite networks capable of regional assessment and analysis of climate and water dynamics at scales ranging from near instantaneous to decadal. Complete characterization of regional climate and hydrological systems, and evaluation of future changes in these systems, would require broad coverage using distributed networks of weather-sensing stations, surface and subsurface water flows, and near-real time processing of data.

- Biodiversity Dynamics***:*** Biological monitoring at the broadest phylogenetic level is one of the core functions of NEON, and one of the unique opportunities of the **NEON** program. Monitoring distributions and abundances across the Tree of Life, including microbes, plants and metazoans has never been accomplished, yet understanding how natural and anthropogenic environmental change affects organisms is a key goal in understanding ecosystem function through time. **NEON** offers the physical sites and the instrumentation to conduct phylogenetically complete monitoring across the Tree of Life.

- Biogeochemistry***:*** The cycles of carbon, nitrogen, phosphorus, many other major biological nutrients, as well as trace elements and pollutants are all changing due to human activity. The dynamics of major biogeochemical cycles have direct implications for human health and well-being, both directly, and indirectly via effects on ecosystem goods and services. The pace and scale of biogeochemical changes is beyond both the time and space scales of many traditional scientific studies, and therefore requires coordinated networks that can effectively document such changes for decades, with high spatial resolution at continental scales. The observational capability of a **NEON** network can provide such data, thereby greatly improving our capability to predict and respond to biogeochemical changes that affect human and ecosystem welfare.

- Biosphere-Atmosphere Coupling: A key component of **NEON** activities will be to sense (assess) fundamental change in integrated ecosystem structure and function.

- Spatial Analysis and Remote Sensing: Regional landscape structure will be characterized for both the core and satellite sites. This will entail a combination of remote sensing and extensive ground truth data collection. Landscape structure includes overall watershed structure, community types, and mosaic (patch) structure. Such data provide the baseline for understanding land cover and land use change at multiple spatial scales.

These comprehensive measurements provide the foundation for addressing questions about biodiversity and ecosystem function, carbon dynamics, invasive species, coupled human-natural systems, ecology of infectious diseases and biogeochemical imbalances. No such combination of intensively deployed instrumentation and analytical capability exists in one place anywhere, let alone replicated across the continent. But, this is the objective for **NEON** to provide the infrastructure needed to understand in detail the causes and consequences of biological change.

Information technology (IT) is by far the key component of **NEON** that will bind together the core and satellite sites of an observatory with those of other observatories across the nation, integrating them into a single, functional research tool. Therefore, considerable planning and documentation has been directed toward IT activities for **NEON** (specifically workshop reports II and VI, http://www.nsf.gov/bio/neon/NEON2.pdf; http://www.nsf.gov/bio/neon/NEON4.pdf.)

To meet NEON Objectives, the functional characteristics of NEON Information Management necessarily include support for: data acquisition—acquiring data through sensors, field measurements and other methods; quality assurance and quality control; storage and archiving, promoting dissemination and access to data, information, and knowledge, integration and aggregation and analysis, synthesis and modeling.

Further details on standard measurements, instrumentation and IT are available in Appendix A.

FY 03

In the FY03 budget request to Congress, NSF requested $40 million for the construction of the first two observatories at $20.0 million each. Funds would be dispersed as $12.0, $12.0 and $16.0 in FY03 through FY05, respectively in Table III.

Table III: Support for 2 NEON Observatories
FY 2003 Request
(Millions of Dollars)

	FY 2003	FY 2004	FY 2005	Total
Construction	12.00	12.00	16.00	40.00
Maintenance, Operations	3.00	6.00	6.00	15.00
Total, NEON	$15.00	$18.00	$22.00	$ 55.00

Complete NEON

NEON would start with the construction of two observatories in FY2003. A possible timeframe to compete the entire 17-observatory network would be seven or eight years. Based on feedback to NSF from the research community, there are 4-5 teams that are currently ready to compete to establish the first two observatories. Numerous other consortia are forming and they are perhaps a year or two behind in the planning process. The goal of the first two observatories will be to demonstrate the feasibility of deploying field instrumentation, gathering environmental data from field based arrays, collecting data simultaneously from geographically distributed arrays, integrating data across diverse types of databases, establishing an informatics infrastructure, and fostering an integrated research program.

MANAGEMENT STRUCTURE

CONSTRUCTION PHASE

The construction phase (Figure 3) will require frequent and direct three-way interaction between NSF, the Fiduciary Entity for an observatory, and once established, the Director of the NEON Coordinating Unit. Also, required at the onset are close interactions among the consortium members, the Fiduciary Institution and the Observatory Director. The purpose of this interaction is to assure that construction stays on-time and on-budget, and that standard instruments, measurements and protocols occur across the network.

Funding for construction will be through a Cooperative Agreement to a single institution that serves as the fiduciary entity for a given observatory. Consortium members will receive construction funds via subcontracts from the fiduciary entity.

NSF management will follow the NSF *Major Research and Equipment and Facilities Construction (MREFC) Management and Oversight Guide*. NEON will be managed by two full-time Program Directors. One will have facilities construction and management experience and will be responsible primarily for oversight of construction through operation. The second Program Director will be responsible for the scientific aspects of NEON.

NEON will have an internal Project Advisory Team (PAT) as specified in the MREFC Facilities Management and Oversight Guide. The PAT has members from the Directorate for Biological Sciences, and the following Directorates and Offices: Geosciences; Office of Polar Programs; Engineering; Social, Behavioral and

Economic Sciences; Computer and Information Science and Engineering; and the Office International Science and Engineering. Additional members include representatives from the Office of Budget, Finance and Award Management; Division of Grants and Agreements; Office of the General Council; and Office of Legislative and Public Affairs. The PAT advises and assists the Program Directors in establishing realistic cost, schedule and performance goals, developing the terms and conditions of Cooperative Agreements, and overseeing the project. The PAT is charged with providing proactive assistance to the Program Directors in moving the project through to completion.

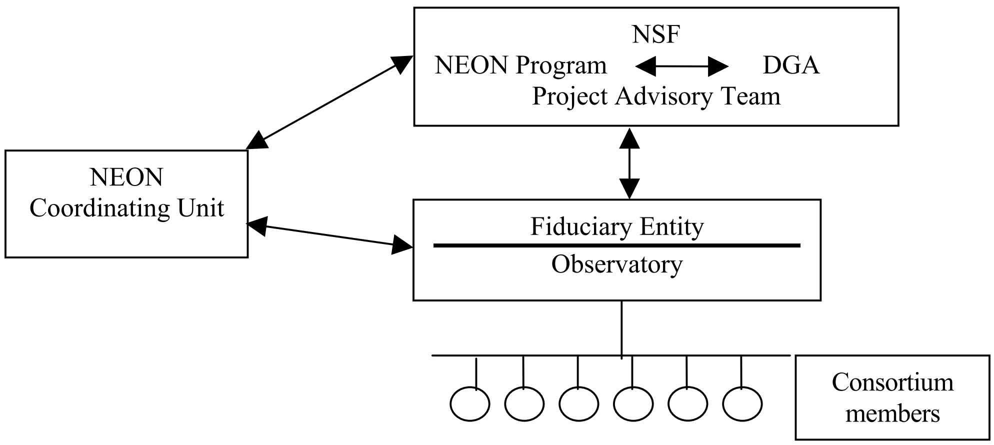


Figure 3. Schematic diagram of the organizational structure of a **NEON** observatory and its relationship to NSF and the NEON-CU during the construction phase.

OPERATIONAL PHASE

The **NEON** Management Workshop (Workshop III) recommended that **NEON** observatories and the entire network adopt the following governance structure (Figure 3).

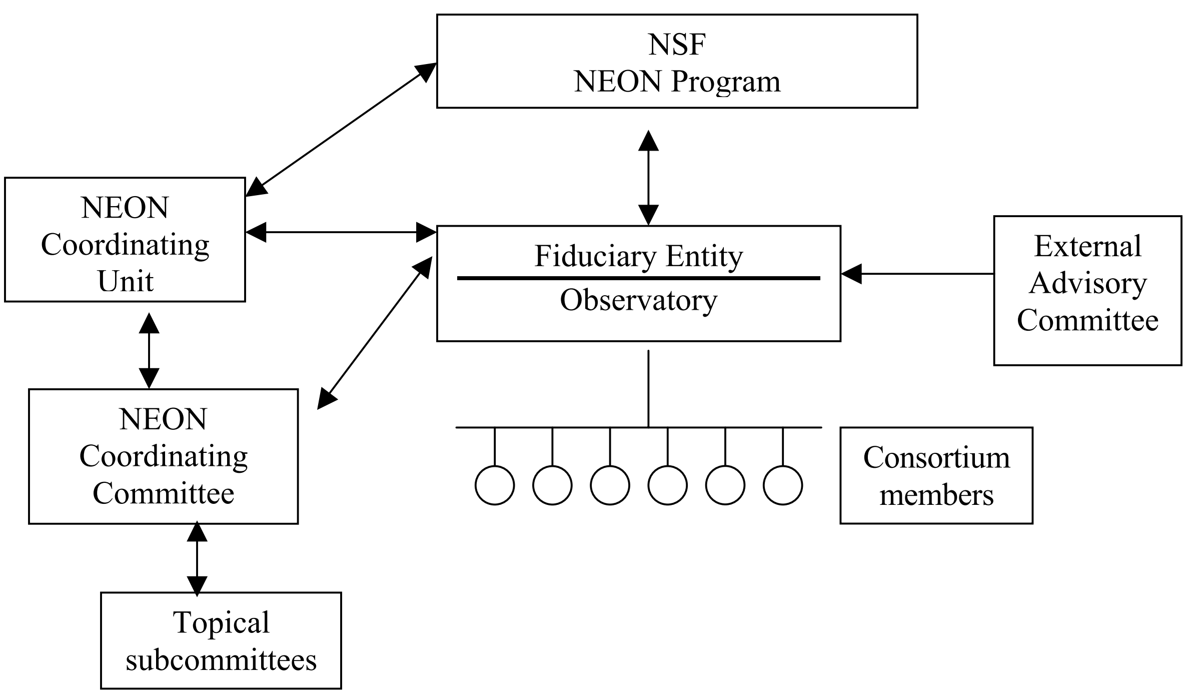


Figure 4. Schematic diagram of the governance structure of a **NEON** observatory and its relationship to NSF, an External Advisory Committee, the NEON-CU, and the **NEON** Coordinating Committee and subcommittees.

The management scheme identifies the key lines of communication and decision-making process for **NEON**. Once operational, each observatory will have an external advisory committee (EAC) to focus on research opportunities, observatory priorities, and observatory management. This EAC may include scientists that are currently using or formerly used the observatory infrastructure, plus other independent advisors as need. Members of this committee will be nominated by the observatory consortium representatives and appointed for three-year terms by the Observatory Director. The EAC may meet only once or twice per year. A committee made up of elected members from the consortium institutions will serve as the Executive Management Committee for the day-to-day operations of the Observatory. This committee will meet biweekly, or more often, as needed.

The **CU** will have the responsibilities described earlier in this report. A coordinating committee will be established to communicate the needs of the individual observatories to the NEON-CU Director and to serve as a conduit of information from the NEON–CU to the observatories. The **NEON** Coordinating Committee (CC) will be comprised of the PI from each observatory, plus the Chairs of various Topical Committees.

Topical Committees will be formed as needed, some will be standing committees (Information Management); others may be temporary (e.g., Net Primary Productivity standards development). An Executive Committee of six members will be elected from the CC membership for three-year terms. This executive committee will regularly interact with the Director of the NEON-CU to formulate policy and management issues. These issues will then be discussed and voted on by the full Coordinating Committee.

This structure has two goals. The first goal is to establish an information pipeline that allows ideas that bubble up from individual observatories to be tested, refined, and then transferred to the full network, when appropriate. The second goal is to develop a management structure that will develop and implement standards across the network of observatories.

Conclusion

The information provided above on NEON's justification, mission, objectives, design, costs and management structure shows that NEON has been developed through a comprehensive and thoughtful planning process, which has involved extensive input from the research community and interaction with NSF. Based on this information, one would conclude that NEON is needed, timely, and ready. Once operational NEON will provide a needed research tool that does not now exist. NEON will allow the ecological research community in collaboration with other scientists and engineers to tackle ecological issues that are important to address now. By pushing the frontier of ecological research out to the regional and continental scale, NEON will stimulate the development of a new generation of research instruments and transform ecological research. NEON is ready for implementation and the research community is ready to use it.

APPENDIX A

Standard measurements, instrumentation and Information Technology

Below is a summary of standard measurements and instrumentation, which has been distilled from the NEON planning workshop reports. This suite of instruments was selected to provide an integrated set of standardized measurements and analytical capability to address the grand challenges in ecology. The standard measurements and instrumentation needs listed in Table II will facilitate quantitative and integrative analyses of (1) climate and hydrology, (2) biodiversity dynamics, (3) biogeochemistry, (4) spatial analysis and remote sensing, and (5) biosphere-atmosphere coupling. These comprehensive measurements provide the foundation for addressing questions about biodiversity and ecosystem function, carbon dynamics, invasive species, couple human-natural systems, ecology of infectious diseases and biogeochemical imbalances. No such combination of intensively deployed instrumentation and analytical capability exists in one place anywhere, let alone replicated across the continent. NEON, by filling this gap, will provide the capability to understand in detail the causes and consequences of biological change.

1. Information Technology (IT)

Information technology (IT) is by far the key component of **NEON** that will bind together the core and satellite sites of an observatory with those of other observatories across the nation, integrating them into a single, functional research tool. Therefore, considerable planning and documentation has been directed toward IT activities for **NEON** (specifically workshop reports II and VI, http://www.nsf.gov/bio/neon/NEON2.pdf; & http://www.nsf.gov/bio/neon/NEON4.pdf.

Given that overarching goals of NEON are to provide data of high utility for addressing critical issues, like the nature and pace of biological change, the information management goals for NEON are:

- **end-to-end quality**—support collection and maintenance of high quality data and accompanying metadata from the field to the laboratory and through analysis and dissemination
- **timeliness**—provide timely and broad community access to NEON data and information (open and real-time data access)
- **relevance**—facilitate knowledge transfer to scientists, decision-makers, and the public (e.g., provide customized views to make data and information, such as summaries, trends, graphics, and visualizations, accessible to these stakeholders)
- **technology leadership**—facilitate NEON network coordination and collaboration (i.e, instrumentation, data collection, and analytical protocols; wireless and automated data collection and processing)
- **interoperability**—provide a tightly coupled national network; interoperability is paramount
- **standardization**—design and develop <u>or</u> identify and adopt data and information standards for core measurements
- **flexibility**—build information management systems that are robust and extensible—which may be best designed through modularity and well designed interfaces among components
- **discovery**—facilitate and enhance the data discovery process

- **security**—provide for secure and long-term access to the data (backup, mirroring)
- **stewardship**—create a national data resource that can be mined for decades to come
- **collaboration**—create an environment for data quality that draws upon collaboration among scientists, technicians, information technologists, and all personnel engaged in the NEON enterprise
- **research leadership**—promote collaborative research into relevant information technologies that meet NEON objectives

For **NEON** to meet its objectives and be successful, the informatics infrastructure will be designed to address the full range of data and information management activities, including the following:

- Data Acquisition—Acquiring data through sensors, field measurements, and other methods.

- Quality Management—Documenting and managing the quality of input data and the curation of data collections.

- Storage and Archiving—Implementing secure local storage and long-term archiving and caching of data.

- Dissemination and Access—Making the data available to **NEON** researchers and the larger research community, including the provision to control access to data as appropriate (see "Data Policy," below) and support for information discovery and data set management.

- Integration and Aggregation—Making data compatible with collections and tools, e.g., co-registration, and preparation of new data products by federating multiple data sets.

- Analysis, Synthesis, and Modeling—To support the investigation and application of the collected data, including standard analysis tools and custom **NEON**-specific applications. Examples of similar custom tools for other domains include the Biodiversity Species Workbench and the Biology Workbench.

Investment in **NEON** IT is of paramount importance to the success of the **NEON** network and the individual observatories as a community resource. The scope of the needed IT activities is broad, including observatory-specific and network-wide activities, activities targeted at supporting specific research projects, and development activities addressing difficult problems that have not yet been solved in information technology.

With respect to the mission of an ecological observatory, it is obvious that the collection and management of information are critical and pervasive activities, and the success of **NEON** will depend heavily on its ability to manage information, from data collection, through analysis, dissemination, and long-term archiving.

Network-wide interoperability in information infrastructure will occur. Automation in data acquisition and an integrated approach to the design, development, and maintenance of the **NEON** information infrastructure will facilitate this goal. A network perspective and a design and development approach that emphasizes modularity and standardized interfaces will be adapted to maximize system flexibility and efficiency. To centralize planning and information infrastructure development, all observatories will actively participate in all aspects of the process. This coordination will provide benefits in terms of economies of scale and quicker technology dissemination and advanced technology development, without compromising the flexibility of an individual observatory.

Balancing the autonomy of the individual observatories with network-level standardization will be a challenging task. This task will be addressed at the inception of the **NEON** network so that individual observatories implement compatible infrastructures. Exploring issues of inter-site compatibility and agreeing on common standards and procedures will reduce the complexities of information management in **NEON** greatly while enabling individual observatories to retain the flexibility to respond to unique site characteristics.

To accomplish the necessary **NEON** functions, the information infrastructure will require a broad suite of integrated technological components, including sensors, communications devices, networks, and computing platforms. This infrastructure will need to support informatics activities that are **NEON**-wide as well as specific to individual observatories. It should also capitalize on existing resources from organizations such as PACI, NCEAS, LTER, the Research Collection Facilities, and others.

The overall system will be robust and extensible, which is best accomplished by modular design and well-defined interfaces between components. For example, although there will be a variety of different field sensors, a standard protocol for the interfaces will be adopted. Under this approach, **NEON** observatories will have the flexibility of installing site-specific sensors while taking advantage of a network-wide collection of protocols interfacing sensors with the information management system. The major components of the informatics infrastructure are the following:

- Hardware—Compute servers, workstations.

- Network—Wireless in the field, Internet2-speed linkage between observatories and other resources.

- Software—Commercial off the shelf (COTS) software will be used whenever possible and custom software developed when needed. Even so, COTS software will require some effort to interface to other elements of the infrastructure.

Implementation of the **NEON** information infrastructure will follow a systematic cycle of activities. This will be a continuous cycle, and there will always be ongoing development activities. Such development will be necessary to ensure that the system remains operational and capable of supporting its mission. Over the planned life of **NEON**, the established information infrastructure will require updating through a systematic cycle of activities that consist of:

- Requirements assessment.
- Design.
- Systems integration.
- Prototype development.
- Deployment.
- Evaluation and feedback.
- Maintenance and upgrades.

Data collection and instrumentation standards will be fundamental to achieving the goal of **NEON** being an integrated national-scale research platform. Therefore, measurement and instrument standards for core data collection and analysis will be imposed from the start on all **NEON** observatories. To enhance data compatibility and to allow cross-site comparisons, all **NEON** observatories will have the following basic instrumentation and analytical capabilities (for details see the **NEON** workshop IV report at http://www.nsf.gov/bio/neon/NEON4.pdf):

- Facilities to prepare samples for genomics analysis;
- Facilities to prepare samples for stable isotope analyses;
- Facilities for determining elemental and biochemical content of biological, soil, or water samples;
- Climate and hydrological instrumentation;
- Remote sensing/GIS facility;
- High speed, high bandwidth telecommunications and networking infrastructure. One member of the management consortium must provide this capability throughout the planned lifespan of **NEON**;
- Computer hardware and software for information management; and
- Biodiversity Observatory capability.

2. **Climate and hydrology**

NEON would provide opportunities to develop instrumentation at the Core Observatory and within satellite networks capable of regional assessment and analysis of climate and water dynamics at scales ranging from near instantaneous to decadal. Complete characterization of regional climate and hydrological systems, and evaluation of future changes in these systems, would require broad coverage using distributed networks of weather-sensing stations, surface and subsurface water flows, and near-real time processing of data. Individual **NEON** observatories will include the following key features:

(1) A spatially distributed network of weather monitoring stations (hereafter called the climate mesonet) connected in near-real time to the core site and to an Internet interface capable of rapid distribution to the community at large. The climate mesonet will support two fundamental aims: (a) the development and deployment of weather and ecological forecasting using current and future generations of coupled biosphere-atmosphere models, and (b) the evaluation of climate and ecological variability at numerous time scales, including decadal trends. The exact number of individual weather stations to be included in the climate mesonet is expected to vary depending on the nature and size of the proposed observatory footprint; however, the network should be capable of characterizing variability in the dominant length and time scales. As an example, in mountainous terrain, stations should be spaced to detect relevant topographic forcings at the diurnal scale. On the Central Plains, stations may need to be more closely spaced, and measurements may need to be collected more frequently, in order to pick up relevant features of the dominant convective motions that drive extreme weather phenomena. Each weather station in the climate mesonet will measure:

(a) radiation (including incoming solar radiation, net radiation and photosynthetically-active radiation),
(b) precipitation,
(c) soil temperature and soil heat flux,
(d) barometric pressure,
(e) wind speed and direction (at minimum of two heights),

(f) air temperature (at minimum of two heights),
(g) humidity (at minimum of two heights).

The measurement of wind speed, air temperature and humidity is intended to provide at least a rudimentary vertical profile capable of being used to estimate sensible and latent heat fluxes according to the "flux-gradient" approach. To accomplish this, humidity sensors will have to be high quality with outstanding accuracy.

(2) A subnetwork of sun photometers to be co-located at some of the weather stations in the climate mesonet. This network is intended to resolve the length scale of atmospheric transmissivity (primarily affected by water vapor) for the purpose of rigorous atmospheric correction of satellite data. The presence of this subnetwork will greatly improve the ability for observatories to analyze remotely-sensed images that are expected to be a critical part of the regional data archive.

(3) A subnetwork of ecohydrologic sensors to be co-located at some of the weather stations in the climate mesonet. The purpose of this subnetwork is to evaluate water and nutrient transport and transformation, and the role of surface and subsurface water in the regional energy budget. Examples of components of this subnetwork are soil moisture profiles, shallow ground water wells, lysimeters for measurement of evaporation, and soil moisture lysimeters for nutrient content analysis.

(4) A broader-scale ecohydrologic network, not necessarily co-located with the weather station of the climate mesonet. The purpose of this network is to characterize the dominant surface and subsurface components of the regional hydrologic cycle, which will permit the understanding of aquatic-terrestrial interactions, hydrologic flow paths and aquatic biogeochemical dynamics. Examples of components of this broader network include stream and river gauges, subsurface gauges (hyporheic gauges), snow surveys and/or remote-sensing. At coastal sites, components may also include high frequency and low-frequency tidal gauges, bathymetric surveys, optical current meters and salinity and temperature measurements. Part of this network may already exist in observatory footprints due to activities from other agencies (e.g., USGS, CUAHSI). Groups are encouraged to work with agencies to integrate new components of the **NEON** ecohydrologic network with existing components.

(5) An intensively instrumented "super-site" will be located at the Core Observatory for the purpose of more intensive and extensive measurements than those taken at the distributed stations of the climate mesonet. Measurements to be included at the Core Observatory super-site, in addition to those of the mesonet stations, are:

(a) UV radiation
(b) aerosol optical depth
(c) diffuse versus direct radiation
(d) boundary-layer profiling
(e) high frequency – high accuracy atmospheric pressure (for use in atmospheric turbulence modeling)
(f) eddy flux measurements of energy, gases and water

To date, no comprehensive co-located network of climate-hydrology instrumentation infrastructure exists. Thus, **NEON** would yield a powerful set of integrated measurements that would be replicated spatially across the network.

3. Biodiversity

Biological monitoring at the broadest phylogenetic level is one of the core functions, and one of the unique opportunities of the **NEON** program. Monitoring distributions and abundances across the Tree of Life, including microbes, plants and metazoans has never been accomplished, yet understanding how natural and anthropogenic environmental change affects organisms is a key goal in understanding ecosystem function through time. **NEON** offers the physical sites and the instrumentation to conduct phylogenetically complete monitoring across the Tree of Life.

Intensive biological monitoring affords the opportunity to track key taxa of societal and economic importance as well. Invasive species, human, livestock and agricultural diseases, endangered species, as well as indicator taxa including amphibians, songbirds and butterflies will provide information that is critical to monitoring ecosystem health of natural and human-modified landscapes. In some cases, existing databases in museums and herbaria collections can provide a historical context that will allow **NEON** monitoring to provide immediate results of societal importance. In other cases, trends and patterns of species turnover and invasion will be generated over the decades-long time scale by the **NEON** site itself. Both will provide invaluable, completely novel levels of information that are critical in managing landscapes now and in the future.

Each observatory will maintain an extensive, structured, hierarchical permanent grid of sampling sites to facilitate coordination among inventories of different taxa. A complex of such grids, representing characteristic landscape units, will be established at the Core Observatory and at some satellite sites. At each site, species composition and community structure will be determined; and these data sets will be thoroughly and accurately GIS-referenced.

Invasive species will be monitored in two ways. First, the extensive grid of monitoring sites will be used as a permanent monitoring network to detect new invasive species. Second, each Observatory will establish a specific monitoring network to assess the distribution, abundance, and population structure of existing invasive species that are deemed to be important in that ecosystem type.

Natural history research collections will be an essential component of **NEON**. They will make essential contributions to the scientific challenges of **NEON** research, in particular biotic inventories and the development of rapid assessment protocols. They will:

- Provide taxonomic guidance for inventories and monitoring, assist in the selection of bioindicator species and in the development of core taxa to be monitored at all **NEON** sites to allow comparisons of habitats and conditions.

- Assist **NEON** research in implementing proper protocols for standards and best practice for managing and maintaining specimen, tissue, bulk sample, and other special collections, including archival-quality housing and durable labeling techniques.

- Employ detailed protocols for standards and best practice for managing and maintaining collection and specimen data, notably through collection databases.

- Provide planning support for appropriate specimen acquisition with regard to type and scope of specimen acquisition and handling.

• Provide guidance on proper specimen identification and follow-up quality control of identifications. Taxon-centered systematists can provide identifications, provide identification training, generate identification tools, and locate specific taxon-expertise world-wide.

4. **Biogeochemistry**

The cycles of carbon, nitrogen, phosphorus, many other major biological nutrients, as well as trace elements and pollutants are all changing due to human activity. The dynamics of major biogeochemical cycles have direct implications for human health and well-being, both directly, and indirectly via effects on ecosystem goods and services. The pace and scale of biogeochemical changes is beyond both the time and space scales of many traditional scientific studies, and therefore requires coordinated networks that can effectively document such changes for decades, with high spatial resolution at continental scales. The observational capability of a **NEON** network can provide such data, thereby greatly improving our capability to predict and respond to biogeochemical changes that affect human and ecosystem welfare.

At a minimum, all **NEON** observatories will measure the inputs, internal dynamics and outputs of carbon, nitrogen, phosphorus and biologically important base cations across the landscape. A biogeochemical strategy will extend beyond the major element cycles, in particular to consider the characterization of fluxes and accumulation of both organic and inorganic ecologically important pollutants.

Each **NEON** observatory will include a continuous documentation of biosphere-atmosphere exchanges of CO_2, H_2O, carbonaceous trace gases, and nitrogen gases using eddy flux techniques in which standards used are consistent with the current Ameriflux network. These measurements will include isotopic characterization as much as possible, and effective landscape-scale estimates of biosphere-atmosphere exchange including data on the vertical structure of the lower atmosphere (e.g. lidar; see climate and hydrology section).

Core site documentation of biosphere-atmosphere exchange via the use of eddy flux techniques will be coupled with a landscape-scale strategy for documenting key components of such exchange, notably net primary production, net ecosystem production, plant and heterotrophic respiration, and the soil flux of important chemically and radiatively active trace gases. In addition, significant efforts will be aimed at documenting belowground production. A rhizotron network that is coordinated at the national level, including the development of new software, will ensure a consistent and effective strategy for cross-site comparison of belowground root dynamics. Documentation of landscape-scale carbon dynamics includes regular measurements of litterfall (where appropriate), decomposition rates and above and belowground pools of carbon.

These ground-based strategies for documenting the carbon cycle can be coupled to remote sensing data that provide annual, spatially resolved estimates of vegetation structure and dynamics. In addition, C fluxes and storage will be documented in aquatic as well as terrestrial systems; for the former, aquatic production will be analyzed using a network of datasondes. As with the eddy-flux measurements, landscape-scale data on the abundance of biogeochemical species should be complemented by isotopic characterization of such species to the maximum extent possible.

Workshop reports recommended that **NEON** observatories participate in NASA’s EOS program, thereby providing them access to remote sensing imagery.

Each **NEON** observatory will document atmospheric inputs of biogeochemically important species in both wet and dry forms. Where possible, it is expected that some of this information can come from existing networks, but these networks will likely need to be augmented, most notably for dry deposition where aerosol chemical and physical properties are to be analyzed. Losses of biogeochemical species will also be documented by coupling to the hydrological and climate instrumentation, and include lysimetry, watershed-scale measurements, and groundwater analyses. In-situ automated sensors grids will provide real-time data on water chemistry at spatial scales and temporal resolutions that do not now exist.

Linkage of **NEON** to other major federal environmental networks and activities, including NASA satellite missions, USGS water quality networks (e.g. NAWQA), NADP, and EPA air quality measurements was highly recommended by the NEON planning workshop participants.

5. **Biosphere-atmosphere coupling**

A key component of **NEON** activities will be to sense (assess) fundamental change in integrated ecosystem structure and function. Therefore, each **NEON** Observatory site will include the following attributes:

Ecosystem metabolism (production) will be measured in each observatory. The quantification of NEP (net ecosystem production) will be a priority, with real-time data if possible. In terrestrial systems, this is best done with flux tower data; in aquatic systems with sonde data. At several intensive sites, NEP will be partitioned into aboveground and belowground components with harvest-biomass type data. A rhizotron network for belowground production will be established at many core sites that represent major vegetation types. This will require additional technical advances and national data coordination before mandating the network nationwide. Litter production will also be quantified as a proxy for aboveground NPP. It should be noted that production assessment techniques will differ across growth forms and ecosystem types, so although there is a mandate to quantify NEP/NPP within each Observatory, the actual techniques used to do so will be specific to regional ecosystem types, yet will be fully compatible.

6. Spatial analysis and remote sensing

Regional landscape structure will be characterized for both the core and satellite sites. This will entail a combination of remote sensing and extensive ground truth data collection. Landscape structure includes overall watershed structure, community types, and mosaic (patch) structure. Such data provide the baseline for understanding land cover and land use change at multiple spatial scales.

Spatial analysis is augmented through remote sensing analysis utilizing a variety spectral and spatial scale observations. Analysis of spatial-temporal dynamics of landscape and land use units can be evaluated at the regional scale with a combination of current satellite (MODIS) and aircraft observations. **NEON** will collaborate with NASA and other satellite-operating entities to provide seasonal and spatial data of various ecological features. Seasonal dynamics of land and aquatic systems (TERRA and AQUA) will be captured through moderate spatial resolution high temporal observations to capture events such as leaf out, algal blooms, plowing events, although these relatively simple sensors provide access to only a small number of biological variables (light utilization, phenology). Land use and land cover change can be derived from existing high-resolution sensors such as LANDSAT and IKONOS.

Landscape patterns and seasonal events will eventually be augmented by development and use of high spectral and high spatial resolution sensor deployment. Current sensors exist which can define landscape-level pattern of vegetation structure and composition, disturbance events, and fine spatial scale pattern of biological activity on land and in water. This instrumentation can be deployed via aircraft platforms. In time, **NEON** will need an airborne hyperspectral imaging spectrometer. Such a sensor can measure a large number of terrestrial and aquatic biological properties, at high spatial resolution. No space-based hyperspectral sensor is currently available on an operational basis. No existing airborne sensor has the flexibility to acquire data over 2-10 sites often enough to provide coverage of the seasonal cycle and interannual change.